

CRAX/CASSANDRA RELIABILITY ANALYSIS SOFTWARE

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*ABSTRACT

Over the past few years Sandia National Laboratories has been moving toward an increased dependence on model- or physics-based analyses as a means to assess the impact of long-term storage on the nuclear weapons stockpile. These deterministic models have also been used to evaluate replacements for aging systems, often involving commercial off-the-shelf components (COTS). In addition, the models have been used to assess the performance of replacement components manufactured via unique, small-lot production runs. In either case, the limited amount of available test data dictates that the only logical course of action to characterize the reliability of these components is to specifically consider the uncertainties in material properties, operating environment, etc. within the physics-based (deterministic) model. This not only provides the ability to statistically characterize the expected performance of the component or system, but also provides direction regarding the benefits of additional testing on specific components within the system. An effort was therefore initiated to evaluate the capabilities of existing probabilistic methods and, if required, to develop new analysis methods to support the inclusion of uncertainty in the classical design tools used by analysts and design engineers at Sandia. The primary result of this effort is the CRAX (Cassandra Exoskeleton) reliability analysis software.

INTRODUCTION

Traditional reliability methods depend on the collection of a large number of samples or observations to characterize the existing condition of the weapons stockpile. These tests provide a snapshot of the existing reliability characteristics of the system. A major objective of recent research is to develop mathematical techniques and computer analysis tools to anticipate stockpile problems before they become critical issues [see Figure 1.]. The assessment of new materials, manufacturing techniques have, in the past, depended on 'average' characterization using deterministic modeling tools. Recent research, however, has focused on developing mathematical methods for incorporating uncertainty in traditional deterministic modeling, in particular, the advanced phenomenological modeling

and simulation techniques used to characterize the physics of the underlying failure processes.

Of particular concern was the development of an analysis capability that would be applicable over the entire life-cycle of the system. An essential element was the ability to incorporate both test data and engineering judgement into the reliability characterization of the material or component being evaluated. Finally, it was important that the method address the sensitivity of the system performance to the uncertainties in the various internal and external model parameters.

An effort was initiated to evaluate the capabilities of existing probabilistic methods and, if required, to develop new analysis methods and software to support the inclusion of uncertainty in the classical design tools used by engineers at Sandia National Laboratories. A series of surveys are being prepared that document the review of existing techniques. The first of these has been completed summarizing the analytical methods developed between 1956-1986¹. The primary result of this effort was the CRAX analysis software.

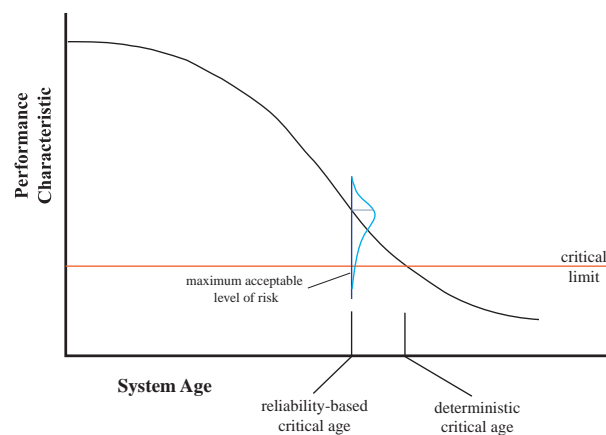


Figure 1. Reliability-based vs Deterministic Performance Analysis

SOFTWARE ELEMENTS

There are three major elements to CRAX: 1) the uncertainty analysis engine – Cassandra, 2) the user interface – also called CRAX, and 3) the physical model. The relationship between these three elements is depicted in Figure 2.

The heart of the CRAX software is the Cassandra uncertainty analysis engine. This engine consists of a number of software routines that permit the user to select a variety of methods for including uncertainty in

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their analyses. A number of first and second order techniques, max-likelihood and a variety of other analytical methods are available for application. In addition, there are options for using a number of pseudo- and quasi-Monte Carlo methods. Specific methods are constantly being updated and improved. (One of the more recent additions is the option to use quasi-Monte Carlo sampling methods rather than traditional pseudo-Monte Carlo techniques².) Cassandra is written completely in C/C++ making the engine very portable.

CRAX/Cassandra has been used with Win95, WinNT, Power Macintosh, Sun, Silicon Graphics and DEC operating systems. In addition, the software has been ported to one of the large tera-flop computers at Sandia.

Access to the Cassandra uncertainty analysis engine is gained via the CRAX interface. The CRAX graphical user interface (GUI) is based entirely on the Tool Command Language (Tcl) and associated Tool Kit (Tk). The use of Tcl and Tk permits the software to be hosted on any platform and provides a great deal of flexibility in accessing the Cassandra uncertainty engine. Rather than trying to develop a complicated GUI for the user that could handle any situation, the use of Tcl/Tk permits the very quick construction of unique interfaces specific to the problem being analyzed. (A basic/generic interface is available for simple analyses.)

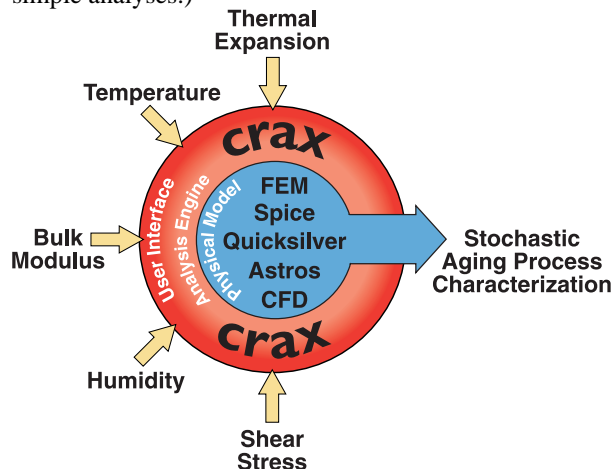


Figure 2. Relationship Between Software Elements

The last element in the CRAX family is the physical model. It was decided early in the development of CRAX to not include any physical modeling tools directly in the software. Rather than develop a modeling tool (e.g. a finite element or thermal analysis package) unique to CRAX, it was decided to let the engineer rely on the existing tools that they were comfortable with and had confidence in. While not the ideal situation in terms of analysis speed, it was felt that for the engineers to become comfortable with

incorporating uncertainty into their deterministic models, it was critical to not stretch their belief system too far. The CRAX GUI effectively 'wraps Cassandra around' the existing analysis software; hence the reference to CRAX as an exoskeleton.

SOFTWARE ACCESSIBILITY

The exchange of information between the CRAX GUI, Cassandra, and the physical model can take many forms. Within CRAX is the capability to either recompile the existing software into the Cassandra engine, thereby significantly increasing computational efficiency, or rely on 'hand-shaking' between the CRAX GUI, the Cassandra engine and the existing software. The Tcl/Tk interface can be modified to handle either of these situations very easily. In addition, Cassandra is platform independent and complies with the Common Object Request Broker Architecture (CORBA) permitting easy interface with many of the new engineering design and analysis software packages (Figure 3). The majority of the commercial software vendors have adopted the CORBA interface standards, e.g. Hewlett-Packard.

In addition, the use of the CORBA interface permits the easy integration of reliability and uncertainty methods into the Product Realization Environment (PRE) at Sandia. The PRE framework has been designed and developed in support of Sandia National Laboratories Product Realization backbone with the goal of providing new and improved information tools to help reduce the time and cost for realizing nuclear weapons components.

The use of a standard interface architecture also permits the easy integration of the uncertainty methods in Cassandra and the routines in the comprehensive optimization package being developed at Sandia (DAKOTA). (It should be noted that there is a 'generic' version of CRAX/Cassandra in which the user types in their own performance function directly into the CRAX interface.)

APPLICATIONS

A number of failure modes have been investigated and include, for example:

1. statistical characterization of the chemical kinetics associated with atmospheric corrosion,
2. thermo-mechanical fatigue of solder connections
3. degradation of polymer seals, e.g. o-rings
4. stress-voiding of interconnects in integrated circuits

In addition, the software is currently being interfaced to an optimal power flow program to assist in identifying elements in the national electrical bulk power system which may be susceptible to sabotage (physical or cyber).

SUMMARY

The CRAX/Cassandra reliability analysis software is constantly being updated as additional existing reliability analysis methods are incorporated into Cassandra and new analysis techniques are developed. Each new design problem brings with it a unique set of input, output and computational requirements. The flexibility of the CRAX interface and the extensibility of the Cassandra uncertainty engine permits the reliability issues to be addressed quickly and efficiently whatever the computational requirements might be. The software continues to provide new insights into issues related to stockpile surveillance that were not possible before.

ACKNOWLEDGEMENTS

This research was conducted with support from the Sandia National Laboratories Enhanced Surveillance Program. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,

for the United States Department of Energy under Contract DE-AC04-94AL85000.

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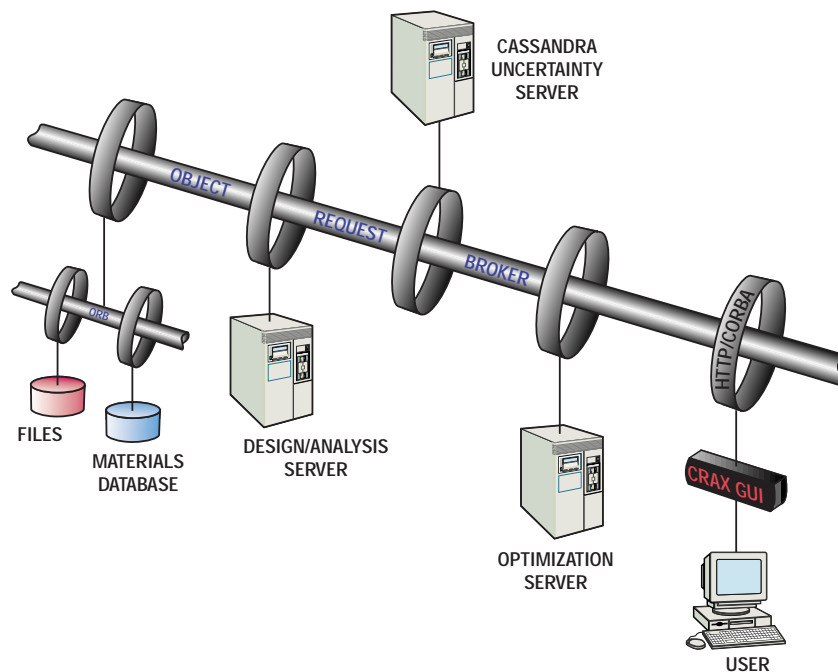


Figure 3. Network Accessibility